HIGH ARCH BRIDGE:
A COST BENEFIT ANALYSIS OF PRESERVATION TECHNIQUES AS APPLIED TO A VERNACULAR CONCRETE STRUCTURE

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Chapter One Introduction

The focus of this thesis is a concrete bridge constructed in 1915 and located on the grounds of the Norristown Farm Park in Montgomery County, Pennsylvania. It is one of seven spans within the boundaries of the 690 acre site, and one of three on the site designed and constructed in the early 1900s to accommodate vehicular traffic over Stony Creek, a tributary to the Schuylkill River and the focus of commercial development in the early history of Norristown.

Once owned and operated as farmland for the Norristown State Hospital, the land is currently rented by the county with fields leased to a farmer for commercial purposes. The bridge is no longer accessible to through-traffic, although it supports the only road looping completely around the park, and is immediately south of a new entranceway currently in the construction phase. This latest change in the use of the site, with the intention of creating a well attended recreational space, depends directly upon the safety and stability of the bridge. No maintenance is recorded in either state or county records, and visual examination of the structure leads one to question the wisdom of increasing activity at this point.

Observation of existing conditions reveals heavy losses of surface material, cracking, spalling, salt damage, and the effects of advanced freeze thaw cycling. The top portion of an abutment has crumbled away, and pieces of decorative elements lie in the creek below. Growth of a floodplain forest partially obscures view of the bridge from below, and vines have embedded themselves in another, still intact, abutment. Salt rings and water stains caused by drainage pipes cover the surface of the interior arches.

Figure 1 High Arch Bridge, west face.

While it is enough to analyze this particular bridge based on the above listed conditions, greater understanding of building technology can be gained by linking High Arch Bridge to the thousands of similar structures which were built in the same material and time period and which now raise the same issues of decay and sustainability. The introduction of reinforced concrete in construction resulted in its extensive use with relatively little understanding of its properties. Consequently, aging structures are exhibiting patterns of deterioration since recognized as typical of the material. Sporadic maintenance, lack of funding, and deterioration over time are all factors to be considered in the treatment of these structures, especially those not normally considered to be of a high style or historically significant. Selection of a vernacular bridge as the subject of an

intensive treatment analysis is intended to underline the prevalence of these structures on the landscape and allow for analyses, diagnosis, and cost efficient treatment possibilities. It supplies the opportunity to test the cost effectiveness of preservation and conservation techniques when applied to actual large-scale structures.

This thesis will provide insight to a previously unexplored topic in preservation practice. Early vernacular structures built of concrete are extremely significant and represent a large and relatively unexamined assemblage on the American landscape. They address issues of function and use, unable to be shut down or abandoned because of the service they perform. For example, in the case of High Arch Bridge, for what little maintenance has been performed on it, the park would be crippled without it. However, the service performed does not warrant financial commitment in the eyes of the "client". It is likely that the least expensive treatment is preferred, with possible work being put off for that elusive "other time". The provision of a range of treatments recognizes this hesitancy and offers alternatives with the intent of facilitating some action toward their improvement rather than their demolition to make way for some new material. Ultimately, the thesis questions what is worth saving and what can be learned from that which is saved.

1.1 Selection of Topic

Since the advent of its large-scale commercial use early in the twentieth century, reinforced concrete has been both a benefit and a detriment to the constructed American landscape. Its ready availability, ease of use, and economy in comparison to other

materials caused it to be the material of choice in numerous structures, particularly in situations where initial cost was the dominant consideration in the construction process. As is often the case, however, the enthusiasm of industry for a new material did not always account for limitations in knowledge and design capability. Thousands of deteriorating structures stand, or barely stand, as proof of this observation. Inappropriate application, poor craftsmanship, and questionable concrete mixes are the cause of failure in structures thought at their inception to be sound and well put together. The range of structures utilizing this new technology in the early part of the century is impressive, including Henry Mercer's Fonthill in Doylestown, Pennsylvania, and Frank Lloyd Wright's Universalist Church in Oak Park, Illinois. The focus of attention has bypassed the more utilitarian example of concrete use, leaving the American landscape with a large body of deteriorating and poorly maintained structures with no clear approach or plan for their rehabilitation. The specific focus upon such a structure for intensive study is intended to emphasize their extreme significance as a precursor to major buildings, and develop a methodology to best treat these early examples of a material so important to the development of the built American landscape.

Selection of a structure for this thesis was guided by the need for a case study typifying structures built at the turn of the century. The significance of High Arch Bridge lies not in any unique architectural characteristics, nor in a prominent architect, but in its similarity to other structures erected in this critical point in history.

High Arch Bridge is not recognized as historically significant in the traditional sense by the Pennsylvania Historical and Museum Commission, nor by the National Register of

Historic Places. The county responsible for maintenance of the bridge does not seek to pursue any label of historic significance, rather, its function as a utilitarian structure is key to its worth on the site. Historic value of the structure and of the material is to be considered in this thesis, however, it is not the dictating force behind the structural evaluation. Issues of cost are second only to those of safety where public use is concerned. When historic value is entered into the equation, evaluation methods are forced to accommodate factors normally not combined, and compromise must be made to efficiently serve the structure, the site, and the client.

1.2 A Discussion of Significance

The designation of historic significance to architectural works as a means of preservation has been common practice since the Historic Sites and Buildings Act of 1935. Documentation has been a recognized necessity since 1933 with the establishment of the Historic American Buildings Survey. Several legislative acts since then have further stressed the value of historic structures as integral to contextual appreciation of the present built environment.[1] Appreciation of industrial structures as worthy of study began in 1969 with establishment, as a complement to HABS, the Historic American Engineering Record. Operated under the authority of the National Park Service, with input from the Library of Congress and the American Society of Civil Engineers, HAER's goal is the documentation of nationally and regionally significant engineering and industrial sites. Written histories, photographs, and measured drawings are used to

[1] Historic Sites and Buildings Act of 1935. Public Law 74-292, 48 Stat. 666.

record "structural, operational, and contextual significance of engineering and manufacturing sites."[2] The founding of HAER is pivotal to the history of bridges, as it valued such structures as significant in the development of American architecture.

Beyond an aesthetic appreciation for their design, sharper focus on bridges was achieved in 1967 with the collapse of the Point Pleasant Bridge, spanning the Ohio River in West Virginia. Poor maintenance practices and an ignorance of corrosion mechanisms resulted in massive structural failure.[3] This immediately spurred the federal government to establish three separate task forces, the aim of which was the determination of the bridge failure, replacement of the bridge, and, most importantly, the investigation and reevaluation of inspection practices of the period.[4] The National Bridge Standards Act established in 1970 by the Federal Aid Highway Act required states to inspect bridges every two years and that inventory data be kept for each bridge.[5]

In contrast to the scrutiny detailed by the agencies listed above upon specifically acknowledged structures, thousands of bridges go unrecognized by HAER and are not protected under the umbrella of federal guidelines. These structures often are old enough to warrant the interest of preservationists but ultimately go unrecorded due to the lack of distinguishing architectural features or documentation. While the structures are maintained within the context of utilitarian use, large-scale or complete examination of their safety and condition is rarely executed due to limitations in awareness and funding.

[2] *HABS/HAER Standards.* (Washington, D.C.: National Park Service, 1990) 3.
[3] M. Levy and M. Salvadori. *Why Bridges Fall Down.* (New York: WW Norton Company, 1994) 126.
[4] Transportation Research Board *Historic Bridges-Criteria for Decision Making.*(Washington, D.C.:NRC, 1983)7.
[5] Ibid, 12.

Loss of these structures due to complacency and poor maintenance is the greatest threat to their existence. Unnoticed material failure leads to damage far beyond cost efficient repairs or treatments. Traditionally held standards of significance, too high to be reached by small scale utilitarian structures, cause them to be overlooked for recognition as a vast body of collected knowledge about material technology and structural durability over time. The significance of these structures lies in their sameness and pervasiveness. They provide a service as tangible insights into the development of the built landscape while serving the needs for which they were originally built.

1.3 A Brief History of the Site

Located on the grounds of the Norristown Farm Park in Montgomery County, Pennsylvania, High Arch Bridge has stood as a span over the Stony Creek since 1915. This tributary to the Schuylkill River appears in documents throughout Norristown's history as the center of industry dating back to the Revolutionary War at which time it was rumored to be the site of a mill used for gunpowder production.[6] The possibility for economic success attracted commerce to the site, leading to a concentration of development and use integral to the growth of Norristown and the surrounding townships.[7] Real estate listings from the period describe the area as fertile, advertising "one of the most productive farms in the country."[8] While perhaps an overstatement, the area is generally accepted as capable of sustaining a high quality of life in the early

[6] Judith Meier. *A Preliminary Report on the Historic District Within the Boundaries of the Norristown State Hospital*, (1986) 4.
[7] Norristown Farm Park Master Plan. Montgomery County Planning Commission, 1992.
[8] Meier, 6-7.

history of the area. Deed transfers and resettlements are on record throughout the history of the land, with the main use being that of farmsteads and mill sites. Stone homes, barns, and outbuildings still extant today lend insight as to architectural styles of many periods.

Evolution of the site in its current form traces to ownership of the land by William Penn in 1689, when it was known as the Manor of Williamstadt. The land was transferred in 1704 to Penn's son, then to Isaac Norris in 1717. The land was divided among the Norris family into seven tracts, and in 1750 the township of Norris was founded.

Ownership of the area shifted for more than a century until, in 1876, an interest in the property was expressed by the Commonwealth of Pennsylvania with Act 89. This legislation was intended to spur the purchase of land for the creation of an asylum serving residents of Philadelphia, Montgomery, Bucks, Delaware, Chester, Northampton, and Lehigh counties, thereby alleviating overcrowding in the almshouses of Philadelphia.[9] Acquisition of land for State Hospital for the Insane of the Southeastern District campus began soon after this motion and continued into the 1960's. Farms were bought and used for medical staff as well as patient housing. The philosophy behind the placement of the hospital in a rural setting was based in popular psychiatric theory of the time, which held that farm work and productive activity was therapeutic in the treatment of mental illness.[10]

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[9] Arthur Noyes. *Penn Pointers*. June 1959. An in-house hospital publication.
[10] David Gollaher. *Voice for the Mad: The Life Of Dorothea Dix* (New York: Free Press, 1995) 102-104.

The pattern of property acquisition accommodated both ward buildings on the south side of the Stony Creek, and the north side where a dairy barn, pasteurizing laboratory, and pig farm were located. Farmed fields, greenhouses, and fruit orchards capitalized upon the pastoral setting, producing enough both to operate a self-sustaining hospital and to be sold on the market. Of the 981 acres eventually bought by the Commonwealth, 831 were worked as farmland.

Changes in treatment ideology caused all institutional agriculture activity to be halted in 1975, disrupting a system of land use and efficiency that had taken years to establish. Drastic reductions in labor availability and product consumption made the maintenance of the farmland unmanageable, forcing the state to seek out alternative use of the property. In 1980, responsibility for 690 acres of land was transferred from the Department of Public Welfare to the Department of Agriculture. From 1985 to 1987, after disputes over leasing agreements ceased all farm operation, the property and structures on it went wholly unused and without maintenance of any kind. Finally, in May of 1987 the land was again transferred, this time to the Department of Environmental Resources, currently known as the Department of Conservation and Natural Resources, Bureau of State Parks. In 1992 the land was leased to Montgomery County Department of Parks for use as recreational space including a nature trail, picnic areas, and visitor center. It is referred to as the Norristown Farm Park. The land is used for park purposes, with the remaining four hundred eighty acres of the site, including part of the dairy barn, leased from the county and cultivated by a commercial farmer.

Adjacent to the Farm Park is the East Norriton Recreational System which includes baseball and soccer fields, and a well used pedestrian trail.

1.4 Private Roads, Service Structures, and Archaeological Ruins

Contained on the property, in addition to the farm houses and hospital wards mentioned above, is a complex infrastructure originally intended to facilitate movement within the hospital grounds and for export of agricultural products to other parts of the state. Access to and from Norristown, the county seat, was and is critical for other parts of the county. While vehicle access to the park is currently limited to a few areas, a system of roads within the farm has been in place since at least the turn of the century. Three bridges, Meadow Bridge, Hospital Bridge, and the focus of this thesis, High Arch Bridge, span the Stony Creek. All three are arched construction. High Arch Bridge is the largest of the three with two arched vaults and two straight spans, while Meadow Bridge has one single low arch and Hospital Bridge dated 1922 has two arches, also shallow. A fourth bridge immediately outside the grounds of the Farm Park, also two shallow arches. is of local stone construction.

Transport activity and commerce was enhanced by the construction of two rail lines on the site, one of which is currently used by Conrail for freight and cargo. One mile of track passing through the site is the only remnant of the now defunct Stony Creek Rail Line, begun in 1868. Five bridges span these two sets of track, and dated plaques place at least one on the site by 1905. Two bridges are of reinforced concrete and one is

built of stone. The remaining two are wooden pedestrian overpasses, both of which are closed.

In the Stony Creek itself, there is evidence of a dam system complete with controls housed in a small slate roofed structure next to the water. Concrete fence posts are visible though out the site, some still set in the ground or obscured by overgrown shrubs and trees or piled in the creek. Ruins of outbuildings are identified by their foundations. The shell of a massive burned barn, originally constructed of wood and concrete, has been used since 1986 to store farm equipment.

CHAPTER TWO METHODOLOGY

Assessment of appropriate repairs and feasibility was determined impossible without a thorough examination of the structure. This was carried out in a variety of ways. A nontraditional but wholly practical approach to evaluation was taken, developing a list of possible approaches based upon ideology, projected use, and varying levels of intervention. Function of the bridge is the most important concern in the strategy, which any historic significance serving a secondary role. The evaluation matrix respects all approaches and ideologies equally, allowing for a clear assembly of repair alternatives with no allowance for superfluous matters.

As stated above, the goal of the study is the development of several realistic repair options with a comparison of their relative feasibility. Thus, the completion of a condition survey was critical to that end. A working knowledge of current condition and deterioration patterns extant on the structure was achieved through a survey based on conditions and terms standardized by the American Concrete Institute. No useful compilation of repair options is possible without such data.

A decision was made to broaden the scope of possible tests to include all that may be appropriate for any given structure, rather than focusing only on those necessary for High Arch Bridge. A full inventory of analytical methods is the result, with explanation given as to what each test is intended to identify.

A thorough search of all documents relating to the bridge was undertaken to discern design details and specific materials used in its construction. It was hoped that an historic context could be created for the role of the structure within the site over time.

While the datestone of 1915 is believed accurate, confirmation of this information was also a research goal.

2.1 Evaluation Matrix: Approaches to Bridge Rehabilitation[11]

The evaluation matrix is intended to represent a range of ideologies within the fields of construction, historic preservation, and conservation.[12] Categories are based upon realistic projected uses for the bridge, ideologies considered in the decision making process, and levels of intervention to be examined. An explanation of viable treatments is offered. Rationalization for rejected approaches is given. Development of the matrix allows for clear comparison in the cost and feasibility of a range of treatment systems.

The first layer of the matrix is based upon the ultimate desired function of the bridge, with options arranged to represent possible future loads on and uses of the bridge. Vehicular use means that the bridge, currently assigned a three ton load rating, will be secured to allow unrestricted vehicular passage. Use of the bridge today is limited to park vehicles and farm equipment. Pedestrian use of the bridge denies access to automobiles and opens the bridge only to foot traffic, respecting the growing popularity of park roads as walking trails. Abandonment of the bridge is complete closure of the structure to transit of any sort.

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[11] *Report of the Study Committee on Architectural Conservation*, (Washington D.C.: Smithsonian Institute, 1977) 45-47. Use of the term "rehabilitation" is based upon the National Park Service definition, "...returning a structure to a state of usefulness by repairs or alterations when its significance does not justify full restoration and when its condition or proposed use precludes preservation in its existing form." A lack of documentation regarding the structure and the presumption that the bridge is not historic allows for use of the term in this context.

[12] For purposes of this study, the term conservation defines the use of material science for maximum retention of original material.

Approaches to repair reflect three intervention ideologies based on current philosophy, technology, and aesthetics: conservation, preservation, and utilitarian.[13] Beginning with conservation, this matrix offers the opportunity to test whether advances in material science conservation may be practically applied to large-scale structures. Laboratory techniques developed to alter the behavior of building materials such as stone, mortar, and wood are here subject to the same cost analysis as accepted construction practices. For purposes of distinction, the term conservation is not used with the European connotation of preservation in mind. Rather, it is the physical addition or application of supportive materials into the fabric of the structure to ensure integrity.[14] Inclusion of material science in the examination of the bridge acknowledges its validity as a viable treatment, however, the use of this advanced science on a vernacular bridge, while possible, is of questionable practicality.

Ideologically, preservation of the bridge dictates that primary focus be placed upon historic value over all other factors. Changes are to be at a minimum, the goal being the retention of bridge character and form as it was built in 1915. As defined by the National Park Service, preservation aims at halting further deterioration without significant rebuilding and encourages only those repairs that do not change or adversely affect the fabric or appearance of a structure.[15] The value of this bridge, in large part, lies

[13] Bernard Fielden, "The Principles of Conservation" in *The Conservation of Historic Stone Buildings and Monuments* (Oxford: Reed Educational and Professional Publishing Ltd. 1994) 22-30. While the bridge is not a monument, Fielden's discussion is relevant to rehabilitation ideology.
[14] Ibid.
[15] *Activity Standards*, section III, part IV(Washington. D.C.: National Park Service. U.S Department of Interior, 21December 1971) 18.

in the technology used to create it, thus causing the examiner to question whether the technology or the structure itself should be the focus of preservation.

The third ideology, the utilitarian approach addresses the desired function of the structure as motivation for any action taken. A determination of appropriate intervention is developed based on the result, with the ultimate concern being that of use. The role of the bridge in daily park operation and the required level of service are weighed with consideration for cost effectiveness above other factors. Efficiency, budget, and value guide the decision-making process in this case, with little regard for historic significance. The best use of building technology for the least cost is of paramount importance.

The level of intervention is established once the projected use and preferred approach are resolved. Simply put, one can do nothing, or one can do something to affect the rate of deterioration on the High Arch Bridge. Along this curve are infinite possible combinations, the compilation of which is deleterious to the creation of an efficient evaluation methodology. A standardization of building assessment interventions is contained within American Society for Testing and Materials publications and has been chosen for use in this matrix as a concise and relevant approach to analysis.[16] The five categories range from "Do Nothing" to acceleration, the hastening of the deterioration process by demolition of the structure. Mitigation affects the curve only slightly. It is any intervention that slows the rate of decline. The life of the structure is prolonged through stabilization. No repair to failing elements or material is made. This step is

[16] Samuel Harris, "A Systems Approach to Building Assessment." *Standards for Preservation and Rehabilitation*, (Philadelphia: ASTM STP 1258, 1996) 137-148.

taken in reconstitution where the clock of the bridge is in effect reset. Repairs made to the structure take it back to a previous state in the aging process. The greater cause of the problem is not necessarily addressed, be it inherent to the design or related to the material. Circumvention of the deterioration introduces new material into the fabric of the structure, with the assumption that material failure is the source of much of the problem. With the introduction of a new material comes a different set of deterioration mechanisms. However, a change in material used in specific areas may be more appropriate than the reinforced concrete, thereby avoiding large-scale loss. Demolition of the structure to accelerate its deterioration is the final option, and while listed in the evaluation process, it is considered extreme within the scope of this analysis.

The layers of use, approach, and intervention are combined in the treatment matrix to present all potential options for the future of the High Arch Bridge. When arranged systematically, it is clear that the majority of approaches, when combined, are incompatible. For example, the first solution, Vehicular/ Conservation/ Do Nothing cannot be carried out. To do nothing demands inaction, while conservation of the structure is an extremely involved process that may at least be described as active. And, since the bridge right now is open only to limited automobiles, some intervention must be made for any change in its use. Only 15 of the 45 options compiled are feasible, and of those, several are possible only in theory or are realistically redundant. From this matrix, an inventory of recommended treatments and costs may be compiled, making possible a systematic analysis to determine the future of the structure.

2.2 Assessment of Condition

Documentation of deterioration patterns in a standard vocabulary is suggested by the National Park Service as the most effective means of recording environmental impact on structures.[17] Based upon this recommendation, an evaluation of High Arch Bridge's current conditions was necessary to accurately assess possible future treatments and repair costs. "The factors that affect the repair objectives include safety and structural integrity, the desired service extension, change in intended use or loading requirements, serviceability, esthetics, and cost."[18] Park authorities have determined the bridge to be structurally sound, at least to the degree that county and farm vehicles are able to drive on it. However, no evaluation of the reinforced concrete had been done at the time this thesis was begun, even though apparent failures of the material, both structural and cosmetic, create a dramatic picture.

Deterioration patterns have not been monitored, thus making accurate determination of material quality difficult. With a construction date of at least 80 years prior to this survey, it was difficult to determine a rate of weathering. A concern for future documentation was yet another factor in the decision to undertake a condition assessment.

Several sources were consulted to develop an appropriate system of analysis.

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[17] Anne E. Grimmer. *A Glossary of Historic Masonry Deterioration Problems and Preservation Treatments.* (Washington, D.C.: Department of the Interior, National Park Service, 1984).
[18] Randall Poston, et al. "Condition Assessment Using Nondestructive Evaluation" in ACI Compilation 34, *Bridge Durability and Performance.* (Michigan: ACI, 1997) 48-54.

Using American Concrete Institute Standards, a working vocabulary of deterioration related terms was assembled.[19] The bridge was evaluated according to these definitions and the degree to which they are evident. Measurements of loss areas were taken, and depths of loss were recorded.

Special note was made of areas where material loss might threaten structural stability, particularly under the bridge deck and at the base of each arch. Links between poor bridge design and extreme failures were made, for example, the inefficient placement of drains has led to the steady erosion of material due to constantly dripping water. Note was made of salt damage, biological growth, and scaling. The structure was scrutinized for signs of replacement material or reconstructed areas.

The lack of documentation regarding construction history of the bridge makes a condition assessment relevant on another level. This record of condition becomes a resource for future researchers of the structure. This basis for comparison allows for determination of deterioration rate and patterns.

A slightly different approach was taken in analysis of the balustrade. Data on over 100 separate elements was recorded and entered on a four point scale, ranging from optimum condition to imminent structural failure. A specific category was created for missing and replaced balusters. The data was assembled in chart form, the number of elements contained in the study suggesting this method of record preferential for interpretation of data. Conditions were described using the same terms as those used to assess the substructure of the bridge.

[19] Report by ACI Committee 201, Kenneth Lauer, Chairman. (Detroit: ACI, 1984 Revision) 3-16.

2.3 RECOMMENDED TESTING

Typically, tests are run as confirmation of diagnoses made in the condition assessment of any site or structure. The intention of testing in this case is to examine both the condition of the material and the structural stability of the bridge. A full inventory of possible tests is presented here for use on any given structure. A recommendation is based upon data compiled from a thorough literature search. Unless otherwise cited, the American Concrete Institute, the American Society for Testing and Materials,[20] and the American Society for Civil Engineers are the three main sources of guidance for these tests.[21] The standardization of tests for reinforced concrete bridges has been established through years of field and laboratory research. This practice aids in the diagnosis of problems, the specification of repairs, and the quantification and qualification of adverse conditions and deterioration present in a structure.[22]

Load ratings, the safe carrying capacity of a given structure, can be established through a number of methods. Maximum capacity, seventy-five percent of total yield strength, and occasionally permissible, and normal operating capacity, fifty-five percent of total yield strength and permitted indefinitely, may both be determined.[23] In instances where full scale load testing may be damaging to the structure, it should not be performed.

[20] The American Society for Testing and Materials, *Concretes and Aggregates* vol. 4.02(Philadelphia, 1990).
[21] ACI Committee 437R (Detroit: American Concrete Institute, 1989).
[22] Poston.
[23] The Organisation for Economic Co-Operation and Development, *Bridge Management* (Paris, France: Road Transportation Research, 1992) 34-36.

Tests of compressive strength determine the strength of in-place concrete, as well as the comparison of concrete in different locations on the structure. The tests include the Swiss Hammer test (ASTM 805), probe penetration (commercially known as the Windsor Probe, ASTM C 803), core tests for compression (ASTM C 42), and ultrasonic pulse velocity (ASTM 597).

The location of steel in a structure is accomplished in several ways. Radiography, the use of penetrating radiation such as x-rays, is recommended to record, through variations in thickness and density, any irregularities under the surface of concrete. Magnetic tests are executed with a hand held pachometer and can be adjusted to estimate bar depth and size, provided they are within seven inches of the exposed concrete surface. Pulsed radar systems, provided the operator is experienced, are useful in revealing rebar location. The preferred investigation for corrosion of reinforcement is half-cell electrical potential testing (ASTM C 876), involving bored holes in concrete and the embedding of probes to determine electrical resistance.

Tests of pH are done to assess the corrosion protection value of concrete, and the susceptibility of steel reinforcement to corrosion. Also revealed is active carbonation present in the concrete. Phenolphthalein is sprayed directly on the concrete and color change is observed. Direct measurement with a pH meter can be taken.

The presence of chlorides, usually leached in the form of de-icing salts, can be determined by the testing of fines. ACI Committee 222 recommends chloride content be lower than 1.5 pounds/cubic yard of concrete. Other salts to test for, both quantitatively

and qualitatively, are sulfates, nitrates, and carbonates. The presence of these may offer clues to sources of infiltration.

A system of petrographic analysis is useful in the determination of air content, cement and aggregate properties, scaling, alkali-silica reactivity, and freeze-thaw susceptibility. Additionally, this program of testing is intended to reveal causes of stress in the material, the degree of damage present, and the quality of concrete as originally cast. Specific aggregate properties tested are particle size, distribution, and composition, and the potential for chemical reaction between the aggregate and cement alkalis, sulfates, and sulfides. Cement properties tested are color and density, homogeneity, settlement, deterioration due to exposure, and the occurrence of fractures in the material. Voids are made known, as are the presence of contaminants, unhydrated material, and admixtures.

Further examination of voids, delamination and other hidden defects to analyze reduced structural properties may be achieved through the application of data gained from sounding tests (ASTM D 4580) and pulse echo radar testing (ASTM D 4748). The sooner an echo returns from the time of transmission, the more likely that an internal crack exists under the surface. Infrared thermography (ASTM 4788) creates a heat generated "picture" of defects.

Permeability is tested to determine concrete's susceptibility to chloride ion intrusion, and the possible effectiveness of sealers and overlays in repair. ASTM recommends a simple absorption test (ASTM C 642). Approximate measurement of

porosity in solids can be tested by water absorption through total immersion, with the application of a formula to determine total mass and void space.

The design of a testing methodology is based on information yielded in the condition assessment. Evidence to confirm the presence of suspected deterioration mechanisms is gained in the performance of a targeted testing program.

2.4 Documentation

Ultimately, documentation of and the lack of available information on High Arch Bridge affirmed the categorization of the bridge as vernacular. Like hundreds of others in Montgomery County, High Arch Bridge was built specifically to facilitate the day to day operation of a large farm complex. The selection of reinforced concrete over other materials was presumably based on low costs and ease in application. Selection was determined not by any great significance within the infrastructure of the Pennsylvania highway system, nor by a well-known architect or innovative construction technology. The value of the bridge for this study is its similarity to other structures on the landscape. In addition to the utilitarian role of the bridge, the 1915 date of construction weighs heavily in its suitability for study. As an old, still functioning structure, High Arch Bridge addresses questions of practical use and preservation, specifically, whether one must be sacrificed for the sake of the other.

Site research was undertaken with an exhaustive search of state and county files. Drawings of the bridge, blueprints, and construction specifications were the target of the survey, with a belief that deterioration mechanisms can be more easily interpreted

through a working knowledge of the bridge's structure. A full investigation of archival documents and architectural drawings began with the Pennsylvania Department of Transportation (PennDOT) Regional Office, Bridge Inspection Division. According to PennDOT, the bridge is not on what is considered to be a full access public road because, in accordance with Farm Park operating regulations, the road is secured with a gate at dusk. For this reason the structure is not within the jurisdiction of PennDOT, and is not subject to federal safety inspection ordinances.[24] Consequently, no written or drawn documentation exists with the Department of Transportation on High Arch Bridge. While unable to aid in archival research, a referral was made by the agency to the Montgomery County

Department of Public Services, Department of Roads and Bridges. The Chief County Engineer asserts, however, that all documentation and safety inspections are the responsibility of the Pennsylvania Department of Transportation.

Acquisition and design of the park was undertaken by the Montgomery County Planning Commission under the leadership of landscape architect Julia Farrell. Inquiries regarding documentation and intended use of park grounds were directed to the Parks Department, specifically Norristown Farm Park Supervisor Edward Brady A meeting with Mr. Brady yielded free access to all records, paperwork, and drawings pertaining to High Arch Bridge.[25] No drawings were found. Few documents held by the county predate the period when park and farm operation shifted from the state. However, maintenance records and inspections from 1986 to 1993 indicate some attempt at regular

[24] James J. Rowan, interview with the author, St. David's, PA. 13 January 1998.

inspections. Upon the suggestion of Mr. Brady, early documentation of the structure was sought at the Norristown State Hospital. A supervised search of Norristown State Hospital drawings, annual reports, photographs, construction specifications, and files of material dating to the founding of the hospital in 1875 was performed, yielding no drawings. Written documentation is minimal and refers to High Arch Bridge only in passing.

The scarcity of information extends to newspaper articles and files at the Montgomery County Historical Society, state archives in Harrisburg, and records of the Pennsylvania Historical and Museum Commission. Written histories of the area tell of the creek, not the bridge, and records of the Pennsylvania Bureau of Dams and Waterways Management hold no information about the structure. Documentation to validate any historic importance of the bridge does not exist, causing its worth to be estimated by its functional value to the site.

[25] Edward Brady, interview with the author, Norristown, PA, 3 November 1997.

Chapter Three Data

Once the systematic collection of information was completed, data was assembled to facilitate the creation of a repair program. The categorization of information began with a description of the bridge to clarify its role on the site and to give a basic idea of scale. Because no drawings and little documentation were found, the description and accompanying photographs hold responsibility for supplying a clear and concise image of High Arch Bridge.

Treatment goals based upon projected use were arranged in a comprehensive chart designed to record every possible combination of use, ideology, and intervention level. This inventory was then expanded to include the specific action implied by each label. In taking a formulaic approach to the design of a treatment program, the range of options becomes one of logic and function, driven by the ultimate goal of a given repair. The matrix allows for the systematic acceptance or rejection of possibilities based upon the feasibility of application on a specific structure.

Dimensional discussion of the bridge was supplemented with a detailed condition assessment and accompanying summary. Areas of loss and active deterioration were recorded based upon careful study of the entire structure, and estimates were made of total material to be repaired or replaced. By necessity, diagnosis of failures were based not on drawings or design plans but knowledge accrued through extensive research on the material and familiarity with the structure gained over the course of the study.

3.1 BRIDGE DESCRIPTION

High Arch Bridge currently serves as the only connector between the Norristown Farm Park and the Norristown State Hospital. All other spans constructed to join roads within the campus during the hospitals' long period of self-sustenance are in a state of advanced deterioration. As the sole link between the two sites, the importance of the High Arch Bridge is clear. Any further significance due to age or material is subordinate to the fundamental role of the bridge, that of a link in the circulation of the park and hospital transportation system.

The bridge, 182' 6"end to end, is positioned north to south over the east-running Stony Creek, and consists of two straight spans and two concrete vaulted arches (Figure 2). Width of the bridge is 26'6", with a roadway through it of 20' 9". The straight spans

Figure 2 Straight spans, east face.

are located on the north half of the structure and measure 23' and 21'4". Four concrete encased I-beams support the reinforced concrete deck which is overlaid with bituminous concrete. Each of the two arches measures 41'6" with supports of 9'6" wide. Four cylindrical pylons stand, in one form or another, at the second of the two vaulted arches, with one at each corner. The purpose of these elements is most likely decorative. Of these pylons, the two on the south end of the bridge are 35' high with a radius of 5' (Figure 3).

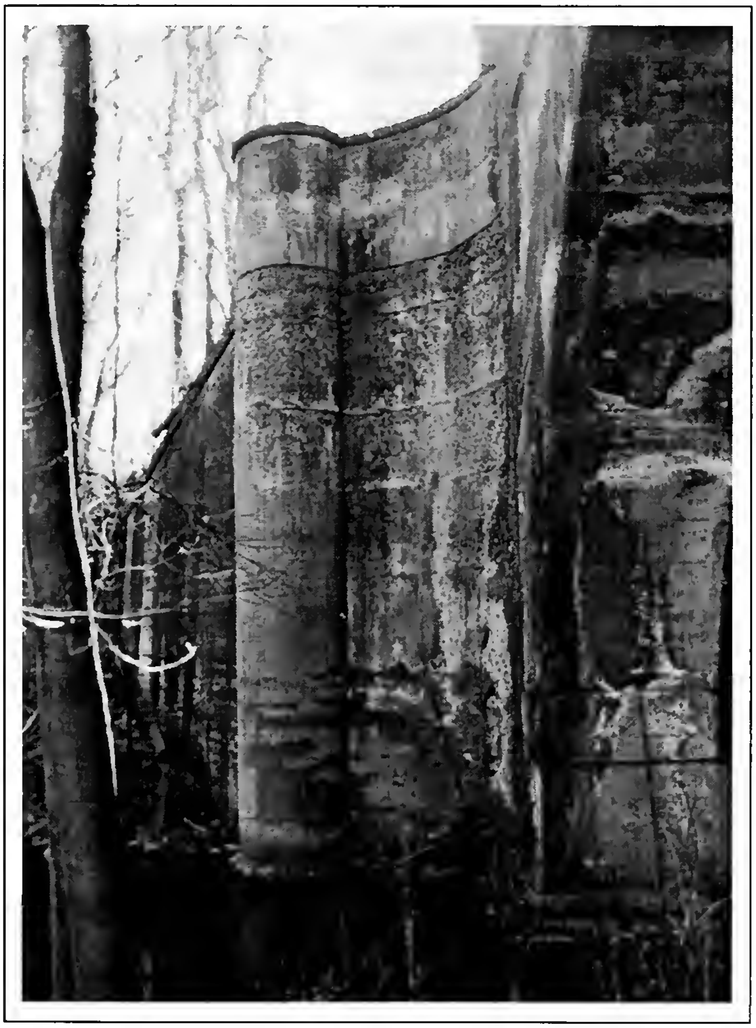

Figure 3 Southeast pylon.

The northeast pylon is no longer in place, exposing a vertical strip of two inch to ten inch mixed aggregate. The top 14' of the northwest pylon is gone, leaving behind an area of impressive overgrowth and bird's nests. A parapet on the deck of the bridge contains eight large and eighteen small posts, evenly spaced amidst 180 balusters (Figure 4).

Figure 4 Balusters, east side of parapet.

This network of vertical elements is linked by twenty-four sections of horizontal rail. The abutments at the north and south end of the bridge consist of two wing walls each, three of which are concrete. The fourth, at the southwest end of the bridge, is of red local fieldstone.

The bridge is made of at least two types of concrete. On the parapet and balusters, a small exposed aggregate is used. Areas of patching and several replacement balusters are filled in with notably finer grain cement. Concrete used in the remainder of

the structure varies in the size of aggregate used, ranging from one quarter inch to the area mentioned above containing stones as large as ten inches. The average size of aggregate throughout the structure is one inch.

The year 1915 is inscribed on a concrete marker above the northern vaulted arch. Because no construction record for the bridge exists in state or county files, this is accepted as the year in which the bridge was either built or completed.

3.2 Summary of Current Conditions

A thorough analysis of the structure, surface by surface, was undertaken to accurately determine the levels and types of deterioration extant on the bridge, with photo documentation supplied for purposes of illustration. A summary of these results is intended to clarify sources of failure on the bridge. Conditions fall into several categories. Interpretation of survey results includes estimated loss amounts due to specific conditions, and areas in greatest need of repair.

The corrosion of steel reinforcement is most visible in the superstructure of the bridge, specifically in the four I-beams that support the bridge deck through both straight spans (Figure 5). One-inch deformed steel rods in the piers of the structure have freed themselves from the concrete in which they were embedded, causing instability to architectural elements they had been designed to support (Figure 6). Exposed metal also protrudes from or is visible corroding within the upper rails of the balustrade (Figure 7). Dark stains on the balusters and posts in the parapet are a secondary failure caused by this corrosion.

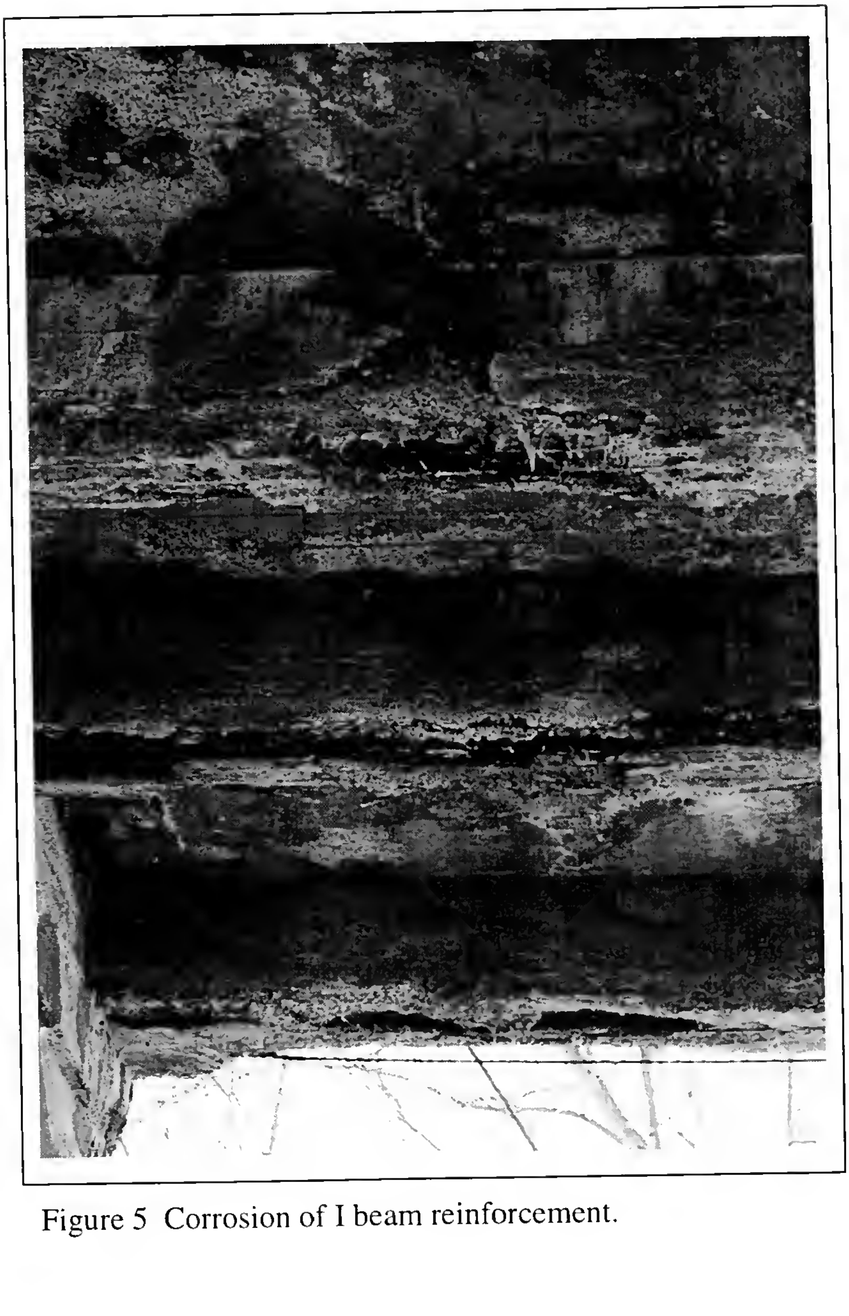

Figure 5 Corrosion of I beam reinforcement.

Figure 6 Deformed steel reinforcement projects from east pier face.

Figure 7 Loss of material due to rebar corrosion.

Material loss, the prevalent and most dramatic manifestation of concrete failure on the bridge, is attributed to man made and chemical influences. Seventy percent of the total surface area of the bridge exhibits losses ranging from one half inch to as deep as seven inches. Shallow losses surround the east and west faces of the vaulted arches, and the upper portion of both interior arches. Loss of the skim coat is visible on several balustrade posts (Figure 8), and on the north and south abutments. Honeycombing of material in the pour process is most evident in the pylons (Figure 9). Exposed aggregate caused by binder loss is visible on twenty percent of the total surface area (Figure 10).

Figure 8 Loss of skim coat on balustrade post.

Figure 9 Honeycombing evident on northwest pylon.

Figure 10 Exposed aggregate on west wall.

Deep losses are present on thirty percent of the structure, the result of several mechanisms. Two to four inch losses are found on the interior walls of both arches and are the result of weephole drainage (Figure 11). These surfaces are never dry, and

several of the weepholes drip constantly. The effects of freeze thaw cycling and erosion have resulted in extreme losses to Pier 1 (Figure 12). All faces of the pier display scaling to seven inches below the surface, with the area of loss extending to a height of ten feet above ground level. Weathering has caused all hard edges and angles on this pier to wear away.

Figure 11 Loss to surface caused by weephole design.

Figure 12 Extreme loss to Pier 1, west side.

Other mechanisms of decay present are less threatening to the stability of the structure. Excessive moisture has caused extensive salt deposits, both in the form of

efflorescence and subflorescence. Heavy buildup of salts on the surface indicates large quantities present in the substrate (Figure 13).

Figure 13 Salts on surface of interior arch wall.

Further evidence of salts are found in the form of gypsum crusts clinging to the areas of loss on the arch interior walls mentioned above (Figure 14). Stalactites cling to the I-beams in the straight spans, emphasizing the action of salts within the deteriorating material.

Figure 14 Gypsum crusts evident around drainage area.

Biological growth and vegetative infestation are present on approximately forty percent of the bridge. It is manifest in the form of green material on the east face of the bridge and throughout the parapet. Lichens ranging in color from dark green to brown are prevalent on the lost areas of Pier 1. The most notable instance of vegetative overgrowth is found on the east face of the second pier in the space formerly occupied by a decorative pylon. Vines and small tree roots are here embedded in the substrate (Figure15). The pylon on the west side of the bridge, its top 14 feet gone, is also overgrown with tall grass and small trees (Figure 16).

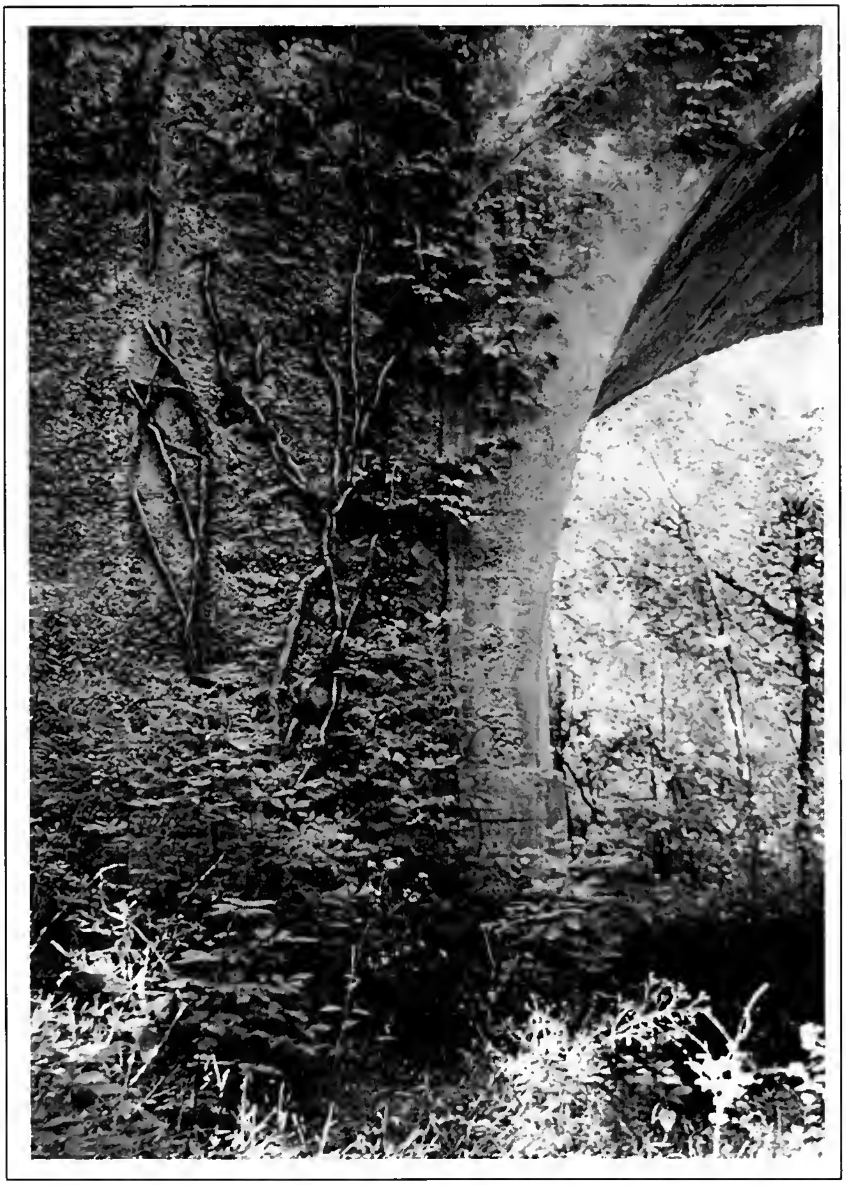

Figure 15 Extreme vegetative overgrowth, Pier 2.

Figure 16 Plant growth on northwest pylon.

Finally, previous repair campaigns have created inconsistencies in the balustrade. Decorative balusters have been replaced in several areas with nine inch rectangular supports, an unfortunate circumstance causing aesthetic disharmony to the overall appearance of the bridge (Figure 16). In other sections of the balustrade, voids exist where no attempt was made to replace lost balusters (Figure 17). Integrity of the fabric and safety of the structure are jeopardized by these losses.

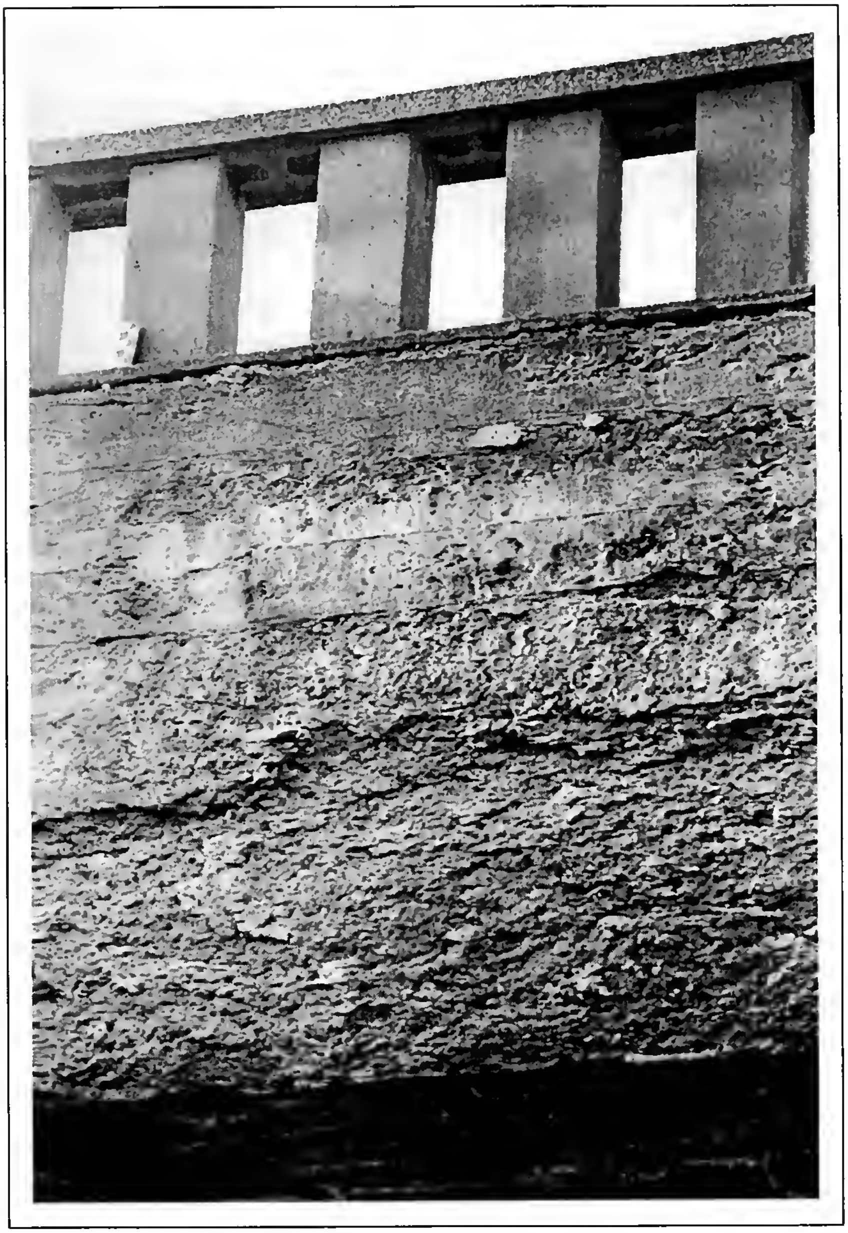

Figure 17 Rectangular replacement balusters

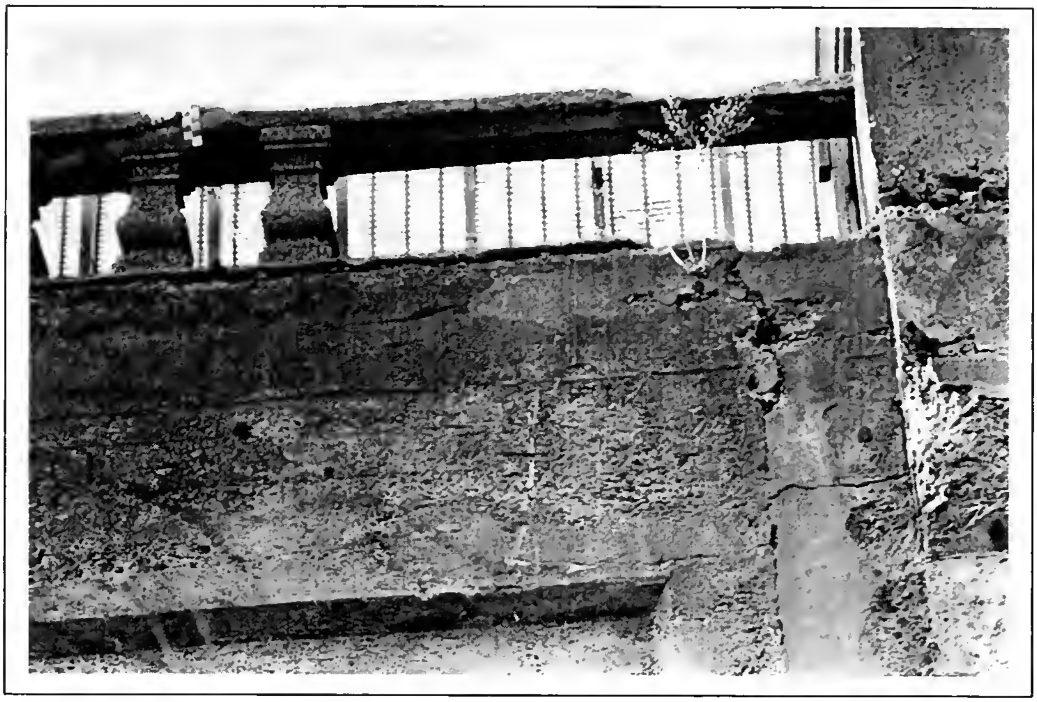

Figure 18 Voids in balustrade.

3.3 APPROACHES TO BRIDGE REHABILITATION

The options for treatment presented below represent a range of ideologies within the fields of construction, historic preservation, and architectural conservation. Categories are based upon realistic projected uses for the bridge, ideologies considered in the decision making process, and levels of intervention to be examined. An explanation of viable treatments is offered, and rationalization for rejected approaches is given, although in several of these cases the logic is clear based on the linked terms.

Key to Evaluation Matrix					
Projected Use		**Ideology**		**Intervention Level**	
A	Vehicular	1	Conservation	a	Do Nothing
B	Pedestrian	2	Preservation	b	Mitigation
C	Abandon	3	Utilitarian	c	Reconstitution
				d	Circumvention
				e	Acceleration

Table 1 Key to Evaluation Matrix

A.1.a Vehicular /Conservation /Do Nothing N/A
Impossible to implement.

A.1.b. Vehicular / Conservation / Mitigation N/A
Currently, the bridge is load rated at three tons. Because mitigation implies only the slowing down of the deterioration process, the structural flaws that warrant this low rating and make the bridge unsuitable for passage cannot be addressed. Thus, this approach is inapplicable.

*** A.1.c Vehicular / Conservation / Reconstitution**
The structure is to be fixed, using conservation methods, so that all vehicles, three tons to 40 tons, are once again able to pass over it.

A.1.d Vehicular / Conservation / Circumvention N/A
This method deals directly with deteriorating concrete, implementing replacement of the material with something less prone to decay. Because conservation by its nature addresses the fabric of the bridge, that is, the concrete, it is not possible to intervene in this way

A.1.e Vehicular / Conservation / Acceleration N/A
It is impossible to both accelerate deterioration of the structure and conserve it.

A.2.a. Vehicular / Preservation / Do Nothing N/A
With no action taken, the bridge is impassable to most vehicles and will eventually deteriorate completely, negating any preservation efforts.

A.2.b. Vehicular / Preservation / Mitigation N/A
Impossible to implement. Slowing down the rate of deterioration is insufficient, answering neither the issue of vehicular use nor that of structural preservation.

***A.2.c. Vehicular / Preservation / Reconstitution**
Allows for repair of the bridge using preservation methods, rendering the structure usable for vehicles.

A.2.d Vehicular / Preservation / Circumvention N/A

Implementation of circumvention methods is in direct conflict with preservation goals.

A.2.e Vehicular / Preservation / Acceleration N/A

By its nature, preservation ideology does not allow for the acceleration of the deterioration process.

A. 3.a. Vehicular / Utilitarian / Do Nothing N/A

Not possible to implement.

A.3.b. Vehicular / Utilitarian / Mitigation N/A

More than mitigation must be done to allow vehicles on the bridge. This treatment is not possible.

***A.3.c Vehicular / Utilitarian / Reconstitution**

Using all methods necessary, repair the structure to allow vehicular passage.

***A.3.d Vehicular / Utilitarian / Circumvention**

If necessary, rebuild part or all of the bridge in a more stable, more easily maintained material.

A.3.e Vehicular / Utilitarian / Accelerate N/A

Acceleration of deterioration, demolition, is inconsistent with the goal of vehicular passage.

B. 1.a. Pedestrian / Conservation / Do Nothing N/A

In conflict here are the principles of conservation and an intervention level that allows no action to be taken.

***B.1.b Pedestrian / Conservation / Mitigation**

The bridge is currently able to accommodate pedestrians. Mitigation of deterioration entails the use of conservation methodology and treatment to slow the rate, thereby stabilizing and lengthening the life of the bridge.

***B.1.c Pedestrian / Conservation / Reconstitution**

Fix the bridge using conservation treatments.

B.1.d Pedestrian / Conservation / Circumvention N/A

Because circumvention implies the use of new materials, it negates the use of conservation treatments and is therefore unable to be implemented.

B.1.e Pedestrian / Conservation / Acceleration N/A

Acceleration of the deterioration process does nor require conservation treatment, and is in fact at odds with the ideology.

B. 2.a. Pedestrian / Preservation / Do Nothing N/A

A decision to do nothing when the structure is in an active state of deterioration is inconsistent with preservation objectives.

***B. 2.b Pedestrian / Preservation / Mitigation**

Entails stabilization of the structure with the intent of extending its use.

***B.2.c Pedestrian / Preservation / Reconstitution**

Improve condition of the structure by undertaking repairs sensitive to the historic value of both the structure and the building material.

B.2.d Pedestrian / Preservation / Circumvention N/A

With circumvention is implied material replacement, thereby incurring unacceptable losses of historic fabric.

B.2.e Pedestrian / Preservation / Acceleration N/A

It is not possible to both preserve the bridge and accelerate its demise.

B.3.a Pedestrian / Utilitarian / Do Nothing N/A

***B.3.b Pedestrian / Utilitarian / Mitigation**

Stabilization for use by pedestrians.

***B.3.c Pedestrian / Utilitarian / Reconstitution**

Repair of the bridge to ensure its continued use and safety as a pedestrian accessible structure.

***B.3.d Pedestrian / Utilitarian / Circumvention**

Replacement of unsound material to the degree necessary to minimize future repair costs and eliminate decay patterns exhibited by this

B.3.e. Pedestrian / Utilitarian / Acceleration N/A

C. 1.a Abandon / Conservation / Do Nothing N/A

***C. 1.b Abandon / Conservation / Mitigation**

Abandon structure and allow to stand as a ruin, applying protective treatments to slow weathering process.

C. 1.c Abandon / Conservation / Reconstitution N/A

Once determined that the bridge is to be abandoned, conservation treatments cease to be an appropriate or practical reality.

C. 1.d Abandon / Conservation / Circumvention N/A

C. 1.e Abandon / Conservation / Acceleration N/A

C. 2.a Abandon / Preservation / Do Nothing N/A

***C. 2.b Abandon / Preservation / Mitigation**

Perform minimal maintenance and allow structure to stand as a ruin.

C. 2.c Abandon / Preservation / Reconstitution N/A

C. 2.d Abandon / Preservation / Circumvention N/A

C. 2.e Abandon / Preservation / Acceleration N/A

***C. 3.aAbandon / Utilitarian / Do Nothing**

Erect a fence for safety purposes and discontinue use of the structure.

C. 3.b Abandon / Utilitarian / Mitigation N/A

In the utilitarian approach, abandonment of the structure ceases all treatment.

C. 3.c Abandon / Utilitarian / Reconstitution N/A

C. 3.d Abandon / Utilitarian / Circumvention N/A

***C. 3.e Abandon / Utilitarian / Acceleration**

Chapter Four Analysis

Data collection and evaluation focused upon current condition of the bridge and the application of repairs based on the three ideologies discussed in Chapter Two. As a result, the repair programs reflect preservation, conservation, and utilitarian influences and the comparative costs of each approach as applied to a structure valued more for its function than for any historic significance. Evaluation of the data was driven by a concern for future use of the bridge, and feasibility of each approach in terms of cost and the extension of use. Knowledge of current repair practices was gained through an extensive literature search, and a professional estimator was consulted to determine the costs of each repair.[26] With this information, it was possible to project realistic costs and the projected longevity of varying approaches.

4.1 Summary of Repair Alternatives

Selection of an appropriate approach to High Arch Bridge hinges upon several factors, the greatest of these being the planned use of the bridge in the development of the Norristown Farm Park. While the bridge was at one time needed for the movement of heavy farm equipment and through traffic, its current use is limited to park vehicles and occasional machinery. Public vehicular access is not a priority; in fact, it is currently discouraged with gates and restrictive signs. Thus, any repairs made with the intent of increasing the vehicular capability of the bridge are unnecessary and contradictory to the projected use of the bridge in park circulation. Plans detail the role of the bridge as a key

[26] Michael Funk, interview with the author, Philadelphia, PA. 25 March, 1998.

component in a bike and pedestrian trail with no change in current automobile access. For this reason, rehabilitation alternatives focus on the bridge as an asset to the park's development as a recreational destination for the community. Abandonment of the bridge, while feasible, is unnecessary. Based upon the condition assessment and visual examination, as well as past inspection records, the rate of deterioration does not suggest imminent collapse. Discontinued use of the bridge clips a major artery, Upper Farm Road, and renders use of the area as a walking or biking trail impossible.

Levels of intervention are based upon the needs of the site and the practical expected use of the bridge. However, all possible treatment schemes must include projected cost and ultimate value of each procedure. Budgetary concerns and the ultimate return of each procedure over the course of time are integral to the decision-making process. Expenditures are weighed against the length of time a given program will sustain the desired effect, that is, extension of bridge use. Implicit in this process is the knowledge that all estimates are supplied as a basis for comparison.

Several methods for the placement of new material are suggested for optimum repair. Hand troweling describes the application of material by hand with a trowel. It is best used in combination with fine aggregates, cement, and non-sag fillers. The material is applied in a series of coats, each being roughened before the next is applied to promote adequate bond.

Wet mix shotcrete involves the application of premixed ingredients including binder, aggregate, admixtures, and water through a pump or pressure chamber. The

material is transported through a hose, compressed air is introduced, and the concrete is "shot" onto the substrate.

As suggested by the name, the form and pump method is a two part process. Forms are built to fit to create confined cavities in areas of loss. New material is then introduced to the area with a pump and hose system. A variety of pumps may be used depending on the concrete mix and aggregate size. Once the material is in place, pressure is exerted to ensure a secure bond between new and existing concrete. In the case of High Arch Bridge, this method is recommended because of its ability to handle repairs of varying depths and aggregate sizes. Further, the use of formwork rather than gravity to hold the repair makes it suitable for overhead and vertical areas.

4.1.1 PROGRAM A

This scheme entails total demolition and hauling away of High Arch Bridge, followed by replacement with a new structure. Conservative estimates given by the Pennsylvania Department of Transportation project the lifespan of a new structure to be at least sixty years, provided adequate routine maintenance practices are performed.[27] The period of sixty years is used as the time of comparison between full replacement and all other methods of repair. It is the time frame in which all repairs are to be assessed.

[27] James J. Rowan, interview with the author. St. David's, PA. 6 March 1998.

Program A		Approximate Quantity	Approximate Costs
Items Program A	Bridge Demolition	1	150,000.00
	Bridge Removal	1	150,000.00
	Bridge Replacement	1	450,000.00
Subtotal			750,000.00
15% Contingency Costs			112,500.00
15% Overhead and Profit			112,500.00
Estimated Costs, Program A			975,000.00

Table 2 Program A

4.1.2 PROGRAM B

This repair procedure is based upon evaluation matrix proposal B.2.b, Pedestrian/ Preservation/ Mitigation. Minimal intervention with a focus on low material and labor costs is emphasized. Testing is not included in this strategy; rather, repairs are based upon visual observation and are to be aesthetic, not structural. Water infiltration has caused significant concrete deterioration and loss in several areas including the parapet and the piers below. The bridge deck is to be removed and replaced, with an increase in the slope to improve drainage. The bridge is to be cleaned with low water pressure to remove light staining and biological growth, making possible an accurate match between original and replacement material. Public use of the bridge necessitates immediate action to the rapidly deteriorating parapet. Missing balusters, scaling rails, and cracking posts are visually and structurally problematic, threatening the safety of pedestrians and creating an eyesore in an otherwise picturesque setting. Corroding reinforced metal supports, where

exposed, will be first measured to determine the level of loss. If more than twenty-five percent of the surface is lost, new metal sections will be introduced for additional support. Otherwise, reinforcement is to be cleaned of scaling and rust using mechanical wire brushing. Replacement of all missing and dissimilar balusters is to be done by an outside contractor specializing in pre-cast elements. Failing rails and posts are to be either repaired or replaced, depending on the rating assigned in the condition assessment.

Mitigation of deterioration includes the development of a cyclical maintenance schedule. Excessive vegetation surrounding the structure is to be removed by park staff, with guidance from a qualified architectural landscaping firm. Currently, view of the bridge is obscured by excessive shrubbery, making any visual examination extremely difficult. Because no substantial structural changes are to be made to the lower portion of the bridge, careful monitoring of condition and deterioration rate is required. Close attention to crack growth, increased depth of loss, and exposed metal will eventually indicate structural weakness and risk to public safety.

Implementation of this plan presupposes a gradual but steady decline in bridge use. After an initial period of stability, diminished capacity will prohibit the crossing of heavy farm equipment by the tenant farmer. Later, lighter equipment including park patrol vehicles will be unable to use the structure. Finally, the bridge will be presumed unsafe for pedestrian crossing. At this point, a decision to demolish and possibly replace the structure will be necessary. The time period for use of the bridge with implementation of Program B is estimated at twenty years based upon current conditions, similar situations, and PennDOT projections.

Program B		Approximate Quantity	Approximate Costs
Items Program B	Deck Repair and Repaving	5830SF	25,000.00
	Baluster Replacement	34	17,000.00
	Upper Rail Replacement	6	5,000.00
	Upper Rail Repair	20	3,000.00
	General Repair, Including Large and Small Posts	365LF	18,500.00
	Cleaning	365LF	10,000.00
Subtotal			78,500.00
15% Contingency Costs			11,775.00
15% Overhead and Profit			11,775.00
Estimated Costs, Program B			102,050.00

Table 3 Program B

4.1.3 Program C

This plan is designed to return High Arch Bridge to its original appearance while enabling continued use as a walking trail. Repairs are to be comprehensive, treating not only the deck of the bridge but also deteriorated material below, including piers, pylons, and walls. Deteriorated material is to be chipped away and filled in with new concrete. Increased load capacity is not the goal; however, prescribed repairs may indirectly address structural issues. This method picks up where the previous repair leaves off. Thus, Program B is a component in Program C.

Levels of loss observed in the condition assessment were used to qualitatively categorize the 20,000 square feet total surface area. Repair costs in these areas vary with

the amount of labor, material , and equipment necessary for improvement of the structure. Category One represents thirty percent or 6,000 square feet of the total surface. These areas exhibit the least amount of loss and require minimal replacement of material. Light cleaning to remove biological growth and patching of small spalls is the only attention required.

Category Two encompasses forty percent or 8,000 square feet of the total surface, and includes areas where depth of loss extends one and one half to three inches into the substrate. Sandblasting, replacement and cleaning of reinforcing steel as needed, and the volume of material to be removed and replaced all make for a more involved and more expensive repair.

In Category Three, concrete deterioration extends to a depth of from four inches to eight inches. Included in this area are the metal I-beams running through the straight spans. Removal of material, cleaning of metal, and replacement of material overhead with shotcrete is exceptionally difficult, causing an increased expense to treatment of this 30% of the bridge, where such an approach is warranted.

Evaluation of condition beneath the surface including voids, composition, and the depth of decay, necessitates several tests. Hammer sounding is done to locate decay areas. Core testing for compressive strength and uniformity of material are required, as is a test for carbonation depth using a phenophthalein solution. Petrographic analysis is called for to determine the concrete used, its condition, and deterioration levels inherent in the material.

After cores have been drawn and prior to major reconstruction, the entire bridge is to be cleaned with water at moderate pressure to remove staining and biological growth. A better match between existing and new material will be achieved if the true color of the concrete is visible.

The size of the project dictates the approach and equipment necessary for removal of material. In this case, the scale of the structure and issues of accessibility indicate that, in addition to the above mentioned sandblasting, a pneumatic chipping hammer is the appropriate tool for removal of unsound material. Care should be taken to avoid underlying reinforcement since there are no drawings to reveal the how the substrate is designed. Where rebar is exposed through material loss, all concrete must be removed from the full circumference of the rebar, allowing for its cleaning and the placement of new concrete material uniformly around it. Rebar replacement is to be determined on an as needed basis. After initial removals of deteriorated concrete, the surface should be sounded for further delaminations and voids.

Adequate bond between existing and new material is critical for a durable repair. This quality is developed through appropriate preparation of the substrate, which must be clean, sound, and roughened to give the new material a surface to key in to. Open pore structure of the substrate, and application of the new material under sufficient pressure to ensure contact are required.

Placement of the new material is determined by location of the deteriorated areas. Almost all deterioration on the bridge is on vertical surfaces, with the considerable exception of the straight span ceilings. The state of the concrete on the underside of the

deck demands that it all be removed from the reinforcement. Wet mix shotcrete applied at moderate pressure is recommended for these ceilings, making application of the material around the metal reinforcement less difficult. A combination of shotcrete and hand troweling are to be used for the resurfacing of exposed aggregate in areas such as the pylons where honeycombing is evident.

With the exception of the above, most of the repair can be executed using the form and pump method of material placement. East and west walls above the straight spans are in need of refacing. Reconstruction of the northwest pylon is recommended for aesthetic purposes. It is not necessary to rebuild its northeast counterpart, however, for purposes of historical accuracy, it may be best to do so.

After this initial expenditure and repair, the bridge is to be maintained as described in Program B. Excessive vegetative overgrowth is to be removed and seasonal observations are to be made with an eye for new cracks and spalls. The bridge will be pressure washed as necessary, to remove staining and biological growth. It is assumed this repair will last a maximum of twenty years before separation between the repair and original material occurs. By that point, load capacity will be significantly reduced. Provisional repairs similar to these may be made over a period of forty years before the concrete is more bad than good and load capacity necessitates closure of the bridge to both vehicles and pedestrians.

Program C			Approximate Quantity	Approximate Costs
Items Program C	Superstructure Repair	Deck Repair and Repaving	5830SF	25,000.00
		Baluster Replacement	34	17,000.00
		Upper Rail Replacement	6	5,000.00
		Upper Rail Repair	20	3,000.00
		General Repair, Including Large and Small Posts	365LF	18,500.00
		Cleaning	365LF	10,000.00
	Substructure Category 1	Removal of Material,Cleaning, and Patching	6030SF	80,000.00
	Substructure Category 2	Removal of Material, Heavy Sandblasting	8040SF	8,300.00
		Repair of Steel Reinforcement		4,200.00
		Surface Patching and Repair of Spalled Areas, Including Form and Pump Where Needed		201,400.00
	Substructure Category 3	Removal of Material,Cleaning, and Patching	6030SF	90,450.00
		Repair of Steel Reinforcement		60,300.00
		Replacement of Surface Material Using Shotcrete and Form and Pump Methods		211,500.00
Subtotal				734,650.00
15% Contingency Costs				110,197.50
15% Overhead and Profit				110,197.50
Estimated Costs, Program C				955,045.00

Table 4 Program C

4.1.4 Program D

Based on a utilitarian approach and capable of increasing the load capacity of the bridge to allow for normal vehicular traffic, this technique involves the maximum removal of material short of total replacement. The superstructure of the bridge, that is, the deck, deck support beams, and parapet including the balustrade and balusters, is to be removed completely. The substructure, including piers, pylons, walls, and abutments, is to serve as the foundation for the new deck and is to be treated as described in Program C. It is recommended that the new superstructure be of simple design and made with concrete. Another option for the new deck is the acquisition of a surplus bridge, such as those sold by the military, thereby cutting down costs dramatically. Longevity of this technique depends upon the quality of repair to the substructure since the superstructure will be built with new material. If repairs are made to the substructure as needed over time, the condition of the bridge should be improved for approximately 30 years before major structural repairs are again necessary.

Costs given for balustrade replacement are averaged based upon three separate estimates made for comparative purposes. The most basic replacement, Level 1, entails a simplistic design installed to increase safety of the bridge with no consideration for appearance and costs approximately \$50,000.00. Level 2, included on the table, is intended to be slightly more compatible visually but ultimately serves the goals of cost minimization rather than cosmetic improvement. At a cost of \$127,000, the new parapet of Level 3 is designed to recreate the character and appearance of the original balustrade using replacement elements identical to the original.

Program D		Approximate Quantity	Approximate Costs
Items Program D	Deck Removal and Replacement	5830SF	25,000.00
	Parapet Removal and Replacement	365LF	90,000.00
	Refer to Repair Program C	20,000SF	651,950.00
Subtotal			766,950.00
15% Contingency Costs			115,042.00
15% Overhead and Profit			115,042.00
Estimated Costs, Program D			997,034.00

Table 5 Program D

4.2 MAINTENANCE

Maintenance costs vary with the repair option employed but must be considered in the decision making process. In all four programs, yearly inspection of the structure at a cost of $2,000.00 must be included. For Programs B, C, and D, the cost of occasional patching and repair is estimated to be $50,000 every ten years. In Program A, with a new bridge, costs are less at $30,000 every ten years. This brings the total for Programs B, C, and D up by an additional $70,000, increases the costs of Program A by $50,000. If applied over a sixty year period, the assumed span of life of a new bridge before major repairs must be done, Programs B, C, and D take on an additional $420,000 in cost, and Program A increase by $300,000.

Estimated Total Costs	**Program A**	**Program B**	**Program C**	**Program D**
Estimated Costs	975,000.00	102,050.00	955,045.00	997, 034.00
Maintenance Costs Applied Over Sixty Years	300,000.00	420,000.00	420,000.00	420,000.00
Total Costs	1,275,000.00	522,050.00	1,375,045.00	1,417034.00

Table 6 Estimated Total Costs

In no instance is the repair of High Arch Bridge an inexpensive undertaking, however, the similarity of costs in Programs A, C, and D is noteworthy, especially when one considers the radically different approaches taken within those programs. It must be stated that Program B, while seemingly the least expensive alternative, does not answer the eventual issue of bridge closure when, having made no major repairs, the structure is no longer passable even by pedestrians.

Chapter Five Conclusion

Analysis of High Arch Bridge demands a focus upon issues of function and use weighed against the determination of historical significance. The value of this structure lies not in any unique attribute or quirk in design. Rather, the abundance of bridges like it on the American landscape recommends it as suitable for an intensive study of issues often overlooked in preservation practice. The early construction date of the bridge allows examination of the use of an early, important material in the construction industry. It is a source of information about early twentieth century building technology in a rural setting, before the mechanization of the construction industry. Further, it is the embodiment of a need fulfilled; that is, a structure designed to serve a specific purpose on the site.

The needs and use of the property have shifted over the course of the century, and High Arch Bridge, while critical for access around the site, is no longer critical to service of the community as a whole. Often in issues of preservation, value of a structure shifts from the function served to historical significance. Retention of historic character rather than consideration for future use becomes the impetus for repair and treatment. In the case of High Arch Bridge and many vernacular structures like it, this transfer of value has yet to be made. The prevalence of such bridges on the landscape of Montgomery County, and on the American landscape makes their unique value difficult to immediately recognize. Because they are still in use, they are seen as permanent fixtures and service structures to be taken advantage of rather than assets to be saved.

The selection of an appropriate ideology to impel the repair of High Arch Bridge, then, must focus upon factors of use and cost rather than of historical significance. Out of respect for the original purpose of the structure, function supersedes form as the rationale behind any repair program. The greatest value of the bridge for the park lies in its continued use over time.

The evaluation matrix serves as a guide to navigate the many theoretical approaches to repair, only a few of which are realistically applicable. Rather than applying an agenda to the process, the matrix begins with the desired result based on a combination of the three discussed factors. From the narrowed list, repairs are assembled to achieve that specific end. Ideology becomes not the guiding force of the repair program, but a secondary consideration. Additional important factors in the selection of a treatment include maximization of the life span versus retention of the maximum amount of original material.

When repair alternatives are compared, and the costs applied over a sixty year span, the least expensive approach is the demolition and replacement of the bridge. However, High Arch Bridge is currently capable of accommodating pedestrian transport and light automobile traffic. It serves the needs of the park and may do so without jeopardizing public safety for the next thirty years. Improvements gained through the implementation of Programs B, C, and D are temporary, and will eventually require the same decisions to be made that are foreseen with a "Do Nothing" philosophy. The bridge is not recognized as historically significant at this time, thus, it does not warrant the cost commitment of intensive preservation or conservation driven repairs. Minimal

intervention serves both the interests of preservation philosophy and of cost abatement. Without factors of historic significance to balance the scale, any practical treatment of the bridge allows it to remain standing as a functioning structure, the use for which it was originally built. Value of the bridge is directly linked to its endurance over time. As a structure built for service to the community, the most appropriate program is one that continues this practice.

Appendix A
Condition Assessment

CONDITION ASSESSMENT

While it is recognized that some action must be taken to restore High Arch Bridge to it fullest function within the landscape, a condition assessment is necessary to determine the levels and types of deterioration present in the structure. To make clear the conditions to be discussed, typical examples have been photographed and are present throughout the structure. Dividing the structure into sections and describing the deterioration characteristics present in each section facilitates a description of all surfaces of the bridge.

Characterization of the main body of the bridge has been arranged as follows:

Northeast Wing Wall
Northwest Wing Wall
Southeast Wing Wall
Southwest Wing Wall

North Straight Span
- North Wall
- South Wall

North Straight Span Deck Support
South Straight Span
- North Wall
- South Wall

South Straight Span Deck Support

North Arch
- North Wall
- South Wall

South Arch
- North Wall
- South Wall

The term "wall" in discussion of North Arch and South Arch refers to the surface extending from ground level to the top center of each arch.
Northeast Pylon

Northwest Pylon
Southeast Pylon
Southwest Pylon

East Wall
West Wall
These are the east and west sides of the bridge.

There are a range of decay mechanisms extant with varying intensities of occurrence. A discussion of conditions will focus upon the dominant mechanism evident within each targeted structural area.

North Wing Wall

The main deterioration to the material in this area is honeycombing of the concrete. Aggregate size is fairly small relative to other pour areas, with an average measurement of one and one-quarter inches by one inch. Insect activity, that is, hibernating black and red insects, is evident in several loss areas. Average size of voids caused by aggregate loss are one inch.

The presence of vegetative overgrowth on the abutment is symptomatic of a greater problem. It indicates poor maintenance practice and neglect to the bridge overall. Vines, small plants, shrubs, and roots surround and in fact permeate the structure. Access to the bridge, both visually and physically, is hampered by the overgrowth.

Northwest Wing Wall

As is the case with its north east counterpart, a concrete curb projects two inches over the abutment wall. Poor drainage of water on this surface has led to a loss of binder

and consequent exposed aggregate. Small areas of efflorescence are visible, as are pockets of aggregate loss. Pour joints can be seen with losses and small cracks on either side of the joints. The greatest depth of loss is one inch and measures roughly two inches in diameter. The overgrowth of vegetation is problematic to wall access. It is not possible to determine where the wall enters the ground due to shrub overgrowth.

Southeast Wing Wall

The condition of this abutment is similar to the previous two. Mild biological growth and green staining are visible, as are voids and crumbling under the two inch overhanging concrete curb. Horizontal bands of salt deposits are present, running parallel to pour lines. Binder has eroded to expose one inch aggregate. Spalling and peeling of the curb surface layer is evident, and may be attributed to poor water drainage on vegetation overgrowth.

Southwest Wing Wall

The southwest wing wall is of red sandstone boulders approximately twelve inches by ten inches by eight inches. It is not clear whether these replace a previous concrete structure. They are dry laid and appear sound with minimal cracking.

North Straight Span

North Wall

Drains in this wall are located sixteen inches above ground level. Losses of surface concrete to a depth of three-quarters of an inch occur with regularity on the wall, and voids caused by aggregate loss are, at maximum, two inches deep. The exposed substrate is actively crumbling, although not to as great a degree as other areas of the bridge, and pits of various shapes and depths are a regular feature. Vertical deposits of salts are evident, presumably caused by water dripping from the deteriorating ceiling. A slim tree stem has affixed itself to the wall. Aggregate is exposed along the upper ten inches of the wall, a result of the two inch projecting overhang.

South Wall

Efflorescence and staining on this wall are evident in horizontal bands on the wall surface. Pale green biological growth is found in conjunction with salt deposits. Losses and voids similar in appearance and size to those on the north wall are present.

North Straight Span Deck Support

Advanced corrosion of structural steel I-beams and consequent spalling of concrete is the most notable mechanism in this area, and possibly the greatest threat to the structural stability of the bridge. The deck serves as a thin support for the above roadway. Four steel beams running from the north abutment to the south bay wall support the bridge deck. These beams are covered with an layer of concrete

approximately one to one and one-half inches thick, followed by a layer of thin metal wire "screen" and a second outer layer of cement. Losses to this system are considerable and abundant. The average area of loss is approximately two to feet along the length of the metal beam and as wide as the beam. Inaccessibility to the metal in the ceiling necessitated visual examination from the ground, making accurate measurement of metal loss impossible. The corrosion has extended to all exposed surfaces, and ongoing crumbling of the encasement concrete indicates that underlying layers are also under attack. The wire mesh used to hold the first layer of concrete in place is in many places completely gone or has detached due to corrosion. Crumbling and spalling occurs throughout the area. Dripping salts form stalactites, and large areas of efflorescence are visible.

SOUTH STRAIGHT SPAN

North Wall

The condition of this wall is comparable to the north wall of the north straight span.

South Wall

Detachment of the surface layer to a depth of six inches characterizes the condition of this wall. An outer surface, presumably a finish coat, of concrete, is gradually detaching to reveal a dry and crumbling substrate. Consequent spalling after loss of the top protective layer is immediate and active. Biological growth covers every

layer of loss with several shades of green, brown, and orange. Lichens speckle the wall near ground level.

South Straight Span Ceiling

Deterioration patterns described for the north straight span ceiling apply to this area as well.

North Arch Interior

Erosion of surface material due to poor drainage and continual water dripping is the primary mechanism evident in this arch, with secondary damage caused by biological growth and extreme efflorescence. Drains are located approximately eleven feet above ground level on the north wall of the arch, and sixteen feet above ground level on the south side. Drain openings measure six inches. Material loss in the form layered spalling is active; a pile of rubble lies at the base of the arch under an area of loss six inches in depth and several feet in diameter. The north wall is considerably more advanced in material breakdown than the south side. Little of the original surface layer is in place on this side, roughly fifty percent of the total surface area of the north wall with the concentration of loss found in the lower portion of the wall. Icicles were observed on the wall at midday in a temperature of forty degrees Fahrenheit. Erosion of corners has removed much of a four foot wide water table at the base of the arch. Few hard edges remain. Extreme efflorescence and crusts are present around drain openings. Stains measure ten inches on either side of each drain. On the south wall, a greater percentage

of original surface area is found although constant dripping of water has eroded the base of the wall, which regularly stands in a shallow pool of water. The center drain on the south wall serves as the center of a large ring of efflorescence and staining. On both sides of the wall, small pieces of metal protrude in varying degrees of corrosion.

South Arch Interior

The south arch spans Stony Creek and is affected by erosion from water and weathering. Loss around drains measures five inches in depth, and efflorescence is found on the wall to a thickness of one-quarter inch in areas seven inches in diameter. Biological growth and staining are present. It is notable that damage to this area is much less severe than that described in the north arch. Cracking and cold pour joints are present , as they are throughout the bridge. Based upon the impressions left from the pouring and setting process, the beams used to form the bridge measured ten inches by three inches. The base of the bridge in this arch has diminished by at least seven inches in several areas due to water erosion.

Northeast Pylon

Notable for its absence, this structure is and the evenness surface indicates the action was intentional. It is possible to see the type of aggregate and metal bar used in the construction process. The exposed concrete contains a variety of aggregate sizes, all of which are present in other parts of the bridge but typically grouped with material of the same size. Here, small pieces of one inch and angular are mixed with stones as large as

seven inches by eleven inches. Mid-range stones are six inches. The mortar itself is spalling and crumbles to the touch. This condition may in part be attributed to metal corrosion. Five feet of one inch square deformed rebar juts out from the surface, and a piece partially buried in the ground indicates that metal loss has been an ongoing problem for the bridge. Examination of this bar reveals rust and minimal pitting but few losses of any great size. Additional information is offered by the several vines that have affixed themselves to the surface of the area. Plant infestation is well illustrated here.

NORTHWEST PYLON

Again, more is expressed by the absence of material than its presence. The top one third of this column is completely gone, and plants grow from the flat surface at the top. Beyond this massive loss of material, the structure appears sound. Uniformly sized aggregate is exposed through honeycombing. The joint where this pylon attaches to the bridge is as wide as three inches. The base of the area has partially eroded.

SOUTHEAST PYLON

Honeycombing exposes an aggregate of one to two inches, with voids of comparable size. Pour joints are clear and deterioration occurs within these boundaries. Losses are greatest parallel to these joints. Loss through spalling is also evident at the top of the pylon, under a five inch projection. Staining due to salts and biological growth is clear. The middle of the column is missing thirty percent of its surface layer, but this is

not the case in the bottom area, indicating a past repair to part but not all of the structure. The base is in the creek and has eroded significantly.

Southwest Pylon

Losses consistent with honeycombing are the primary deterioration mechanism. Only a small part of this base is in water, diminishing the affects of weathering and erosion. Pour joints are again the target of spalling and voids. The surface layer is intact and shows little of the surface damage evident in the south east counterpart. Vertical voids caused in the pour process are present, as is the case in the two other remaining pylons.

East Wall

The condition of this wall varies from north to south. Divided into sections, the north portion of the wall encompasses north bay and south bay. Extreme material loss at edges where north and south span deck supports meet the wall is evident. Corners and hard edges are gone due to erosion and crumbling, a mechanism still active and exacerbated by metallic corrosion. Exposed aggregate is detaching in layers, threatening the stability of the bridge. Losses measure to a depth of five inches. Biological growth and mild efflorescence are visible on the pylon dividing north bay and south bay. North arch is contained in the center portion of the east wall. The missing pylon is the most notable structural loss. Losses are average within the context of the bridge overall, with corners and hard edges worn away through erosion. A carpet of biological growth

characterizes the surface of the south arch. Surface loss of material is minimal. On both the east wall and the west wall, poorly attached and deteriorating posts in the above balustrade contribute to a condition of structural impermanence. Voids as large as one foot and several inches deep are visible from the ground, as are bricks and new material set in place to slow the process of loss.

West Wall

Damage to the above parapet is the main source of instability on this side, followed by exposed aggregate and erosion. Surfaces in the north portion are spalling in layers. The greatest depth from surface to sound substrate is six and one-half inches. Biological growth has covered all layers, and the condition continues in the center of the bridge. Honeycombing and lost binder expose voids one to two feet in diameter and to a depth of two inches. Pour joints are clear, with small cracks and voids concentrated around them. Large areas of exposed aggregate and vertical honeycombing characterize the south area of the wall. Little damage to the arches on this wall is exhibited, although mild efflorescence and staining exist.

APPENDIX B
CONDITION ASSESSMENT OF BALUSTRADE ELEMENTS

BALUSTRADE ASSESSMENT

An assessment of balustrade elements was undertaken with the intent of itemizing specific points of deterioration extant on the parapet of the bridge. Cataloguing of all elements individually was completed based on which side of the bridge the element is located. The balusters and sections were recorded from north to south on both sides of the bridge. An "E" means east and a "W", west. The appropriate architectural definition was used to further classify each piece. "P" means post, "S" means section of balustrade Levels of deterioration are placed on a numerical scale, with a rating of "one"(1) signifying fair condition with some staining, biological growth, or hairline cracks present. A "two"(2) indicates advanced decline of the element, including the presence of larger cracks, flaking, or disaggregation, or some combination of these conditions. Possible structural failure is given a rating of "three"(3). Corrosion of metal reinforcement, spalling, and detachment of material to the point of imminent structural failure are all included in this category. The classification of "four A"(4A) indicates that an original baluster has been replaced with a rectangular element constructed of a fine grain cement. Missing balusters with no replacement element are given a rating of "fourB"(4B) , and "b" means baluster. Upper and lower rails are used to connect posts. The number one to 13 placed after "P" or "S" indicates which of the 26 posts or sections is being evaluated, just as the number one through nine after a "b" indicates a specific baluster within each section. For example:

ES7 b2 refers to the east side of the bridge, rail section seven of 13, baluster number two.

WP 9 refers to the ninth post of 13 on the west side of the bridge.

CONDITION ASSESSMENT OF BALUSTRADE ELEMENTS		
Assessed Element	**Rating**	**Comments**
E Guard Rail	3	Delaminated surface layer to a depth of .5" with additional losses to a depth of 1.25". 75% of surface coat is lost.
EP1	3	Loss of surface layer to a depth of 1.5".
ES1 Upper Rail	3	Corrosion of .5" metal rebars is evident, with .0625 cracks on rail surface running parallel to the bars below. Severe flaking and loss of concrete is apparent with a patch extending 4' along the length of the baluster and 10" wide. A metal bar with concrete attached protrudes from the rail.
ES1 b1	1	Balusters in good condition with minimal biological growth and staining. Structurally, however, metallic corrosion has led to detachment of the balusters from the upper rail, revealing a .25" gap between rail and baluster. This gap has been filled with mortar.
ES1 b2	1	
ES1 b3	1	
ES1 b4	1	
ES1 b5	1	
ES1 b6	1	
ES1 b7	1	
ES1 b8	1	
ES1 b9	1	
ES1 Lower Rail	3	Spalling of surface layer to a depth of .75".
EP2	3	Pattern cracking in pedestal of post, .125" at widest point.
ES2 Upper Rail	2	
ES2 b1	4A	Replacement balusters constructed of fine aggregate cement. 8.5" on all faces. Good condition, minimal staining and biological growth with one exception
ES2 b2	4A	
ES2 b3	4A	
ES2 b4	4A	
ES2 b5	4A	
ES2 b6	4A	
ES2 b7	4A	Biological growth on W face.

Assessed Element	Rating	Comments
ES2 Lower Rail	3	Cracking and spalling of surface with losses of .75" in depth.
EP3	3	Advanced deterioration of E face jeopardizes stability and indicates imminent collapse of element.
ES3 Upper Rail	2	Crack .25" a widest point extends length of rail. Smaller cracks run parallel to metal rebar below. .125" crack spans the width of the rail, 7" away from EP4.
ES3 b1	1	
ES3 b2	1	
ES3 b3	1	
ES3 b4	1	
ES3 b5	1	
ES3 b6	1	
ES3 b7	1	
ES3 Lower Rail	3	Pattern cracking, spalling.
EP4	3	Advanced deterioration of E face jeopardizes stability and indicates imminent collapse of element.
ES4 Upper Rail	1	
ES4 b1	1	Biological growth evident on base of baluster.
ES4 b2	1	Biological growth evident on base of baluster.
ES4 b3	1	Biological growth evident on base of baluster.
ES4 b4	1	Biological growth evident on base of baluster.
ES4 b5	1	Biological growth evident on base of baluster.
ES4 b6	1	Biological growth evident on base of baluster.
ES4 b7	1	Biological growth evident on base of baluster.
ES4 Lower Rail	3	Spalling and cracking.
EP5	3	Cap gone, .125" crack in base at SW edge.
ES5 Upper Rail	2	
ES5 b1	4B	
ES5 b2	4B	
ES5 b3	4B	
ES5 b4	1	
ES5 b5	1	
ES5 b6	1	
ES5 b7	1	
ES5 Lower Rail	3	Traces of lost balusters remain. 2" wide spalled patch runs the length of rail.
EP6	2	Minimal deterioration when compared to other posts. Staining on S face from rebar in ES6 upper rail.

Assessed Element	Rating	Comments
ES6 Upper Rail	1	
ES6 b1	1	
ES6 b2	1	
ES6 b3	1	
ES6 b4	1	
ES6 b5	1	
ES6 b6	1	Pronounced dark staining at base.
ES6 b7	3	Pronounced staining at base. Spalled area on lower rail threatens stability of element.
ES6 Lower Rail	3	Cracks, spalling, surface loss.
EP7	2	
ES7 Upper Rail	1	
ES7 b1	1	
ES7 b2	1	
ES7 b3	1	
ES7 b4	2	Staining from corroding metal in upper rail.
ES7 b5	1	
ES7 b6	1	
ES7 b7	1	
ES7 Lower Rail	3	4' loss of edge in front of b1 - b4
EP8	3	Losses on E face threaten structural stability. Biological growth, staining on S face.
ES8 Upper Rail	2	Areas of patching with fine grained cement. Gaps of .25" are evident between rail and baluster.
ES8 b1	1	Staining W face.
ES8 b2	1	Pronounced dark staining covers body.
ES8 b3	1	Staining concentrated on base of element.
ES8 b4	1	Pronounced dark staining covers body of baluster.
ES8 b5	1	
ES8 b6	1	
ES8 b7	1	
ES8 b8	1	
ES8 b9	1	
ES8 Lower Rail	3	6" spalled patch at b6 threatens structural stability of section. Further cracks and spalls are present on W face of the rail.
EP9	3	Rebar exposed on S face. Large loss on S side where upper rail was attached.
EP9 Upper Rail	4B	
EP9 b1	4B	
EP9 b2	4B	

Assessed Element	Rating	Comments
EP9 b3	4B	
EP9 b4	4B	
EP9 b5	4B	
EP9 b6	4B	
EP9 b7	4B	
EP9 b8	4B	
EP9 Lower Rail	3	Spalled patch measures width of rail by 18".
EP10	3	Large loss on N side where upper rail ES9 was attached. Crack between post and pedestal. Spalls were pedestal meets deck.
ES10 Upper Rail	2	Crack in rail parallel to metal reinforcing bars. Small cracks perpendicular to rail.
ES10 b1	1	
ES10 b2	1	
ES10 b3	1	
ES10 b4	1	
ES1O b5	1	
ES10 b6	1	
ES10 b7	1	
ES10 Lower Rail	3	Spalling. Loss of W edge where rail meets bridge deck.
EP11	3	Advanced deterioration of E face jeopardizes stability and indicates imminent collapse of element. Biological growth.
ES11 Upper Rail	1	
ES11 b1	3	Stability threatened by deteriorating lower rail.
ES11 b2	1	
ES11 b3	1	
ES11 b4	3	Stability threatened by deteriorating lower rail.
ES11 b5	3	Stability threatened by deteriorating lower rail. Fine grained cement surface. Possible replacement element.
ES11 b6	1	Fine grained cement surface. Possible replacement element.
ES11 b7	1	Fine grained cement surface. Possible replacement element.
ES11 Lower Rail	3	W face completely lost due to spalling, which is undermining stability of balusters.
EP12	3	Advanced deterioration of E face jeopardizes stability and indicates imminent collapse of element. Biological growth.
ES12 Upper Rail	3	Spalling of underside of upper rail. Metal reinforcement bars are corroded.

Assessed Element	Rating	Comments
ES12 b1	1	
ES12 b2	1	
ES12 b3	1	
ES12 b4	1	
ES12 b5	4A	
ES12 b6	4A	
ES12 b7	4A	
ES12 b8	4A	
ES12 b9	4A	
ES12 Lower Rail	3	Spalled. Extreme loss of material has caused removal of b5 - b9.
EP13	3	Cap gone. Spalled edges. Biological growth. Deterioration of E face jeopardizes stability of element.
SE Pylon Wall	2	Loss, exposing aggregate and actively crumbling concrete. Spalling of surface layer, rounding of hard edges due to loss.
W Guard Rail	3	Total E face measures 71" x 22". Area of loss due to spalling measures 48" x 22" and is to a depth of 1.25".
WP 1	3	Pattern cracking. Detachment of .5" surface layer, W face. E face loss area measures 27" x 18". S face loss area measures 6" x 7".
WS1 Upper Rail	2	Corroded reinforcement bars exposed on underside of rail. Material loss has led to detachment of balusters from rail with a gap at greatest point of 1". Cracks of .0625" extend 24" in length parallel to rebar. Secondary cracks of equal length.
WS1 b1	1	Brown gray stain, N face top.
WS1 b2	1	
WS1 b3	1	Biological growth E face and N face. Main growth found on body of baluster.
WS1 b4	1	Biological growth E face and N face. Main growth found on body of baluster.
WS1 b5	1	
WS1 b6	1	
WS1 b7	1	
WS1 Lower Rail	3	Spalling at rail, exterior corner
WP2	3	Advanced deterioration of W face jeopardizes stability and indicates imminent collapse of element. Biological growth.

Assessed Element	Rating	Comments
WS2 Upper Rail	2	Corrosion of reinforcement bar. Crusts on underside of rail.
WS2 b1	1	Biological growth concentrated on base.
WS2 b2	1	Biological growth concentrated on base.
WS2 b3	1	Biological growth concentrated on base.
WS2 b4	1	Biological growth concentrated on base.
WS2 b5	1	Biological growth concentrated on base.
WS2 b6	1	Biological growth concentrated on base.
WS2 b7	1	Biological growth concentrated on base.
WS2 Lower Rail	2	Spalling extends under base of b1
WP3	3	Advanced deterioration of W face jeopardizes stability and indicates imminent collapse of element. Biological growth.
WS3 Upper Rail	2	Exposed metal in spalled patch on E face.
WS3 b1	1	
WS3 b2	1	
WS3 b3	1	
WS3 b4	1	
WS3 b5	1	
WS3 b6	1	
WS3 b7	1	
WS3 Lower Rail	3	Deterioration of W wall of bridge is causing losses to lower rail from the bottom up.
WP4	2	Minimal pattern cracking evident in top of post. Some material loss at NE edge.
WS4 Upper Rail	3	Fracture of rail to a depth of 1.25" where joined with WP4. Smaller cracks parallel. Flaking to the point of disaggregation.
WS4 b1	2	Pronounced biological growth.
WS4 b2	2	Pronounced biological growth.
WS4 b3	1	
WS4 b4	1	
WS4 b5	1	
WS4 b6	2	Pronounced biological growth.
WS4 b7	2	Pronounced biological growth.
WS4 Lower Rail	3	Spalling of rail jeopardizes stability of b5 - b7.
WP5	3	Advanced deterioration of W face jeopardizes stability of element. Cracks where WS4 rail meets post. .125" crack on S edge of cap travels toward peak of post. .

Assessed Element	Rating	Comments
WS5 Upper Rail	2	40" crack, partially patched with cement, on E edge of rail.
WS5 b1	3	.25" gap between upper rail and baluster. Unseated from lower rail, turned 15 on base.
WS5 b2	3	.25" gap between upper rail and baluster. Unseated from lower rail, turned slightly.
WS5 b3	3	.25" gap between upper rail and baluster.
WS5 b4	3	.25" gap between upper rail and baluster.
WS5 b5	3	.25" gap between upper rail and baluster.
WS5 b6	3	.25" gap between upper rail and baluster.
WS5 b7	3	.25" gap between upper rail and baluster.
WS5 Lower Rail	3	Spalling.
WP6	3	Advanced deterioration of W face jeopardizes stability and indicates imminent collapse of element.
WS6 Upper Rail	2	Crack where upper rail meets WP6. Material loss to .5" in depth. Vegetation attached to underside of rail.
WS6 b1	1	
WS6 b2	1	
WS6 b3	1	
WS6 b4	1	
WS6 b5	1	
WS6 b6	1	
WS6 b7	1	
WS6 Lower Rail	3	Surface loss .75" thick. Vegetation, 2 tree roots, wedged between rail and b2, b3. Spalls to W face.
WP7	2	
WS7 Upper Rail	2	Spalled patch 3" x 2" reveals rebar on E face. Fissure runs length of rail, .25" at widest point.
WS7 b1	1	Element unstable due to deteriorating lower rail.
WS7 b2	1	Element unstable due to deteriorating lower rail.
WS7 b3	1	Element unstable due to deteriorating lower rail. Gap between element and upper rail.
WS7 b4	1	Element unstable due to deteriorating lower rail. Gap between element and upper rail.
WS7 b5	1	Element unstable due to deteriorating lower rail. Gap between element and upper rail.
WS7 b6	1	Element unstable due to deteriorating lower rail.
WS7 b7	1	Element unstable due to deteriorating lower rail.

Assessed Element	Rating	Comments
WS7 Lower Rail	3	Loss of material between WP7 and b1. Advance spalling threatens baluster stability.
WP8	2	Cracking and detachment where WS7 rail joins post. Crack at corner.
WS8 Upper Rail	2	Patching material on E face. Cracks in three areas of rail, parallel to rebar and .0625" wide. One of three cracks patched.
WS8 b1	1	
WS8 b2	1	
WS8 b3	1	
WS8 b4	1	
WS8 b5	1	
WS8 b5	1	
WS8 b6	1	
WS8 b7	3	Structurally unstable.
WS8 b8	3	Structurally unstable.
WS8 b9	3	Structurally unstable.
WS8 Lower Rail	3	Extreme loss in rail threatens stability of balusters. Aggregate exposed.
WP9	3	Flaked cap, loss of SE and SW edges. Spalling where WS8 upper rail meets post. Staining.
WS9 Upper Rail	3	Spalled E edge reveals reinforcement bar. Small cracks parallel to reinforcement bar.
WS9 b1	1	Detached from upper rail.
WS9 b2	1	Detached from upper rail.
WS9 b3	4B	
WS9 b4	4A	
WS9 b5	4B	
WS9 b6	1	Detached from upper rail.
WS9 b7	1	Detached from upper rail.
WS9 b8	1	Detached from upper rail.
WS9 b9	1	Detached from upper rail.
WS9 Lower Rail	3	Loss of surface layer at base of b8 and b9. Cracking. Biological growth.
WP10	1	
WS10 Upper Rail	1	
WS10 b1	1	
WS10 b2	3	Baluster turned on base.
WS10 b3	2	
WS10 b4	1	
WS10 b5	1	
WS10 b6	1	

Assessed Element	Rating	Comments
WS10 b7	1	
WS10 Lower Rail	3	Spalling and loss of surface layer. 2" loss between WP10 and WS10 b1. Further loss of rail begins at b7 and extends to WP11, N face.
WP11	3	Material behind post gone, W face.
WS11 Upper Rail	2	
WS11 b1	1	Biological growth at base.
WS11 b2	1	Biological growth at base.
WS11 b3	1	Biological growth at base.
WS11 b4	1	Biological growth at base.
WS11 b5	1	Biological growth at base.
WS11 b6	1	Biological growth at base.
WS11 b7	1	Biological growth at base.
WS11 Lower Rail	3	Delamination of surface layer. Material lost between WP11 and b1, also between b7 and WP12.
WP12	3	While physical condition of post itself is good to fair, losses to W bridge face threaten stability of post overall.
WS12 Upper Rail	3	Corrosion and deterioration spreading up from underside of rail.
WS12 b1	1	
WS12 b2	1	
WS12 b3	4A	
WS12 b4	4A	
WS12 b5	4A	
WS12 b6	4A	
WS12 b7	4A	
WS12 b8	4A	
WS12 b9	4A	
WS12 Lower Rail	3	Extreme loss, no flat surfaces remain and aggregate is exposed to a depth of 2".
WP13	3	Biological growth on Eface. Staining on underside of cap. Evidence of recurring vegetation.
SW Pylon Wall	2	Loss, exposing aggregate and actively crumbling concrete. Spalling of surface layer, rounding of hard edges due to loss.

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